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TRANSFER OF HABITUATION OF MOTION SICKNESS ON CHANGE IN BODY POSITION BETWEEN VERTICAL AND HORIZONTAL IN A ROTATING ENVIRONMENT*

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SUMMARY PAGE

THE PROBLEM

This experiment was conducted in a circular rotating room 20 feet in diameter. A unique feature was the provision for subjects to walk and carry out their tasks while horizontal to gravity and at right angles to the axis of rotation. This ability to "walk along the wall" was made possible by the use of air-bearing supports and custom-fitted articulated fiberglass molds. Efforts were made to ensure a degree of comfort and level of activity in the "horizontal mode" fairly comparable to that in the "vertical mode." Four subjects participated in two experimental trials involving habituation to the artificial force environment with the room rotating at 4 rpm. One pair initially in the horizontal mode was changed to the vertical mode in the middle of the perrotation period; in the second experiment they began in the vertical mode. The order was reverse for the second pair.

FINDINGS

The changing symptomatology with regard to motion sickness and postural equilibrium yielded information supporting the following statements. Susceptibility to motion sickness was similar in the two orientational modes. Adaptation and habituation with respect to motion sickness in one orientation mode transferred to the other mode. Vestibular habituation in the horizontal mode ensuring freedom from symptoms of motion sickness did not prevent ataxia on change to the vertical mode. In the "start-vertical" mode habituation of motion sickness and postural disequilibrium was concurrent. The postrotatory perseveration of postural habituation to the rotating environment for as long as 36 hours after the cessation of rotation, by restricting the subjects' activity, shed some light on the underlying homeostatic mechanism and indicated the experimenter's control over the dynamics of this process. Within the limitations of this experiment the findings indicate that habituation of motion sickness acquired in the Slow Rotation Room with a subject parallel to the axis of rotation transfers to the orientation with subject at right angles to the axis of rotation, the situation in a rotating spacecraft. Our findings with respect to postural disequilibrium indicate that simulation of spacecraft conditions in the laboratory will, at best, be poor but that elucidation of the underlying mechanisms is possible.

ACKNOWLEDGMENT

We gratefully acknowledge the splendid cooperation of the subjects and the assistance of the technical staff.

INTRODUCTION

Previous reports from this laboratory have described the symptomatology and associated phenomena manifested by persons exposed in a slowly rotating room (SRR) which simulated in some important respects conditions in a rotating spacecraft (3, 13, 15, 18, 20). Nearly all of these manifestations were the result of Coriolis accelerations generated by bodily movements in the rotating environment. The symptoms characteristic of motion sickness had their genesis in the vestibular organs stimulated in a bizarre manner when the head was moved out of plane of the room's rotation. Difficulty in walking had its genesis both in the vestibular organs and in nonvestibular proprioceptor systems. Through the mechanisms of habituation and adaptation the manifestations of motion sickness soon disappeared, and ataxia was greatly reduced unless the stressful stimuli were severe.

In two important respects conditions in the SRR mentioned above did not simulate those in a rotating spacecraft. First, no attempt was made to simulate subgravity conditions, although the subjects were required in some experiments to remain near the center of rotation to minimize the level of centripetal force. This was a significant limitation inasmuch as the influence of g loading on vestibular responses has been demonstrated beyond doubt (1, 2, 10, 16, 19), and evidence is accumulating that susceptibility to motion sickness is altered as a function of the gravitoinertial load.

A second aspect not simulated is related to the difference in body orientation in the SRR where man is parallel to the axis of rotation when upright and that in the rotating spacecraft where he would be at right angles to this axis. This factor is important for two practical implications, namely, whether this difference affects susceptibility to side effects and whether there is transfer of habituation from one orientation mode to the other, e.g., between SRR and spacecraft.

In the experiment now to be described, a comparison was made between the effects of exposure in the SRR with man parallel and those when he was at right angles to the axis of rotation. Although exposure in the horizontal mode simulated to a small degree subgravity conditions, the present experiment did not feature this aspect. Rather, attention was focused on motion sickness, ataxia, and the phenomenon of transfer of habituation. An incidental finding involving homeostatic mechanisms is of scientific interest.

PROCEDURE

General Plan

Four subjects were divided into two pairs, and each pair participated in two experiments carried out over a period of three months. Experiments involving the same pair were separated by thirty-five days or more to minimize order effects. Except for the initial five-day rotational trial, the period of rotation was four days in each of the

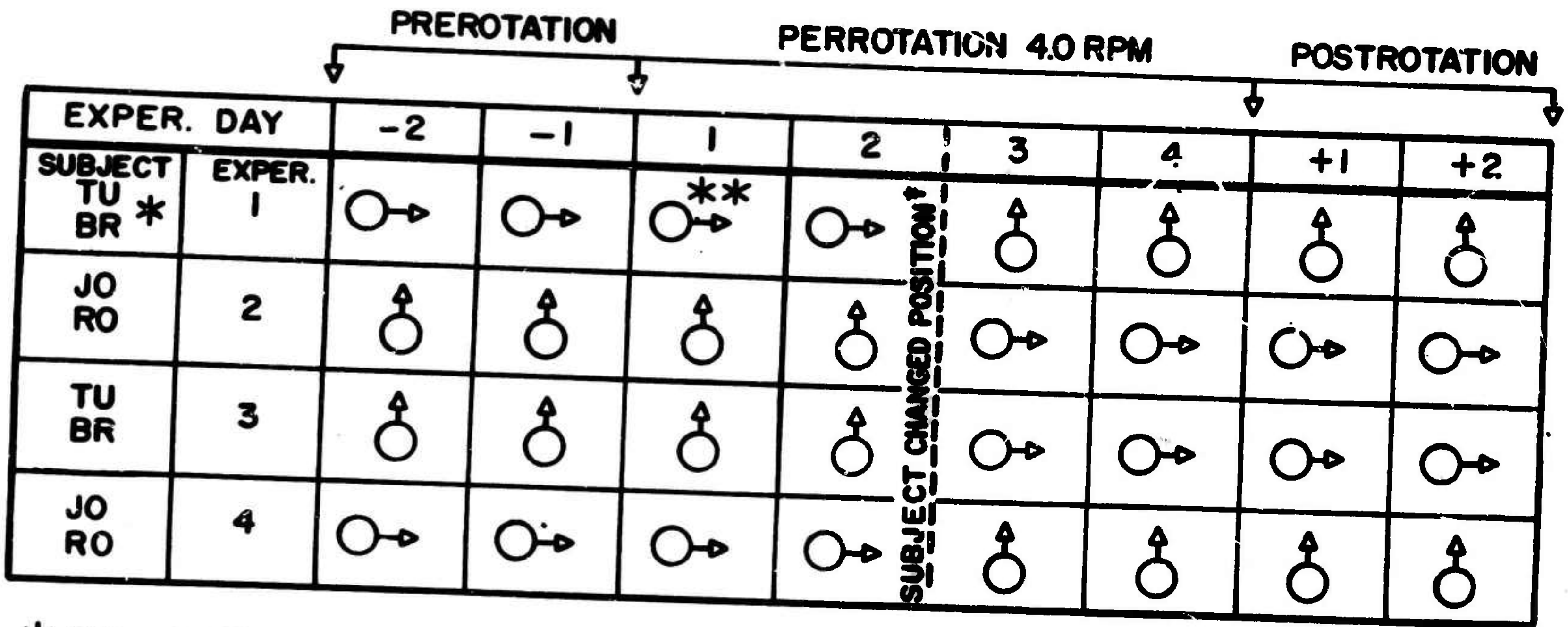
experiments and was preceded and followed by control periods of two days. The level of stress chosen was sudden exposure to an angular velocity of 4 rpm which past experience indicated would evoke mild symptoms. One pair of subjects was first habituated to rotation in the "start-horizontal" mode, then changed to the vertical mode in the middle portion of the perrotation period; in their next experiment they were first habituated in the "start-vertical" mode. The order was reversed for the second pair. The design dealing with these features is shown in Figure 1 where the four experiments are listed in chronological order.

Exposure in the horizontal mode posed a difficult operational requirement because of the need to ensure a degree of comfort and level of activity comparable to that provided the subjects when they were in the vertical mode. This was accomplished by encasing the subject in an articulated fiberglass mold and supporting him on air bearings at right angles to the axis of rotation; this would accord with his orientation in a rotating orbiting spacecraft.

The daily schedule of events and tests was as follows:

0730	Awakened. Urine collection, clinical evaluation, motion sickness questionnaire
0830	Breakfast
0900	Clinical and behavioral tests Blood samples ECG and tilt table test if subjects in vertical mode In middle of perrotation period, change in mode Forced head movements "Ball toss" "Reaction time" Hand steadiness Time estimation Hand dynamometer
1200 - 1400	Luncheon. Recreation
1400 - 1730	Behavioral tests; exercise if in horizontal mode Math test Logit "Panel test" "Cap screw test" Exercise
1730 - 1830	Free time
1830 - 2200	Dinner. Recreation
2200	Retire

Departure from this routine mainly involved free-time activities. Baseline measurements were made on prerotation day -2 (daytime only) and on day -1, and rotation began around 0930 on day 1. There was no interruption of rotation except momentarily in the third experiment when the emergency switch was pressed accidentally. Following cessation of rotation, tests and measurements were continued during postrotation day +1 and the daytime portion of day +2. A tight scheduling of events for the entire day was planned partly to avoid boredom. Some of the "tests" were in effect tasks designed to keep the subjects occupied and moving their heads. Such tasks are indicated in the daily schedule by quotation marks.



* TU and BR spent 3 days in horizontal mode during perrotation phase in first experiment.

** When in the horizontal mode, during a 24-hour period subjects spent between 5 ½ and 6 ½ hours in the air-bearing device, between 6 and 10 minutes upright, and the remaining time on a bunk.

† Occurred around 0930 hours.

Figure 1

Design for Exposure to Stress in the Slow Rotation Room

Subjects

Four Navy enlisted men participated as subjects. A comprehensive medical evaluation revealed no significant abnormalities, and the pertinent findings are summarized in Table I. All had previously participated in experiments in the SRR and were practiced in the methods used, but none was aware of the goals of the experiment. The experimenters were DE, a physician 30 years of age, and RI, an assistant 45 years of age. Both were above average in susceptibility to SRR sickness.

Rotation Device

The experiment was conducted in a circular windowless room 20 feet in diameter, 10 feet high, and without any central supporting members. It had a direct-motor drive capability of controlled angular accelerations between 0.1 and 15.0 deg/sec/sec, with maintenance of angular velocities between 2 and 200 deg/sec with an accuracy of ± 1.0 per cent. Rotation was counterclockwise and continuous at 4.0 rpm, and the accelerations at onset and cessation of rotation were approximately 4.0 deg/sec/sec. The 10,000-pound payload was more than sufficient to provide for operation in the "housekeeping mode" and for the air-bearing devices described below. The communications systems and bioinstrumentation facilities were not taxed in this experiment. A sample-ejector device permitted off-loading of small objects during rotation.

Air-Bearing Device

The requirement was to provide decent living and working conditions with the subjects horizontal with respect to the axis of rotation. The main features were 1) air-bearing supports for two subjects within articulated fiberglass body molds ensuring comfort and freedom of movement (Figure 2); 2) a level polished surface over three fifths of the floor space; and 3) a walkway on the wall (Figure 3) with exercise steps. That the requirement was, eventually, met was demonstrated by the absence of complaints of the subjects who spent approximately six hours a day in the air-bearing device (ABD) carrying out the required tests. During the remainder of each twenty-four-hour period they were vertical six to ten minutes and recumbent the rest of the time.

Force Environment

A subject living in a rotating environment, such as that generated by the SRR, is subjected to a complex array of accelerations consisting of the acceleration of gravity, the centripetal acceleration generated by rotation, and the Coriolis accelerations generated by simultaneous motions of room and occupants. Except for the acceleration of gravity, all these accelerations would be acting upon an astronaut in a rotating spacecraft. These accelerations will be discussed with emphasis on differences between man static and dynamic and between the horizontal and vertical modes.

Table I

Clinical Findings in Four Subjects

Subject	Age Sex Health	History Disease Injury	Auricular Findings: Aud. Test (V. Békésy) R	Aud. Test (V. Békésy) L	S - Canal Threshold Caloric* R	S - Canal Threshold Caloric* L	Otolith C-R Index+ Min of Arc
BR	20 M Good	None	N	Med. Notch 6 kc	36.4	36.4	337
JO	22 M V. Good	None	N	N	36.0	36.2	289
RO	19 M Good	None	Sl. Notch 4-6 kc	Sl. Notch 4-6 kc	36.4	36.6	382
TU	20 M V. Good	None	N	N	36.0	36.2	521

*In deg C. Minimal cooling of exit temperature of water (irrigation for 40 seconds) causing nystagmus.

+One-half the sum of the maximum counterroll on left and right tilt (up to 64° except BR 50°). Typical values, 240-480.

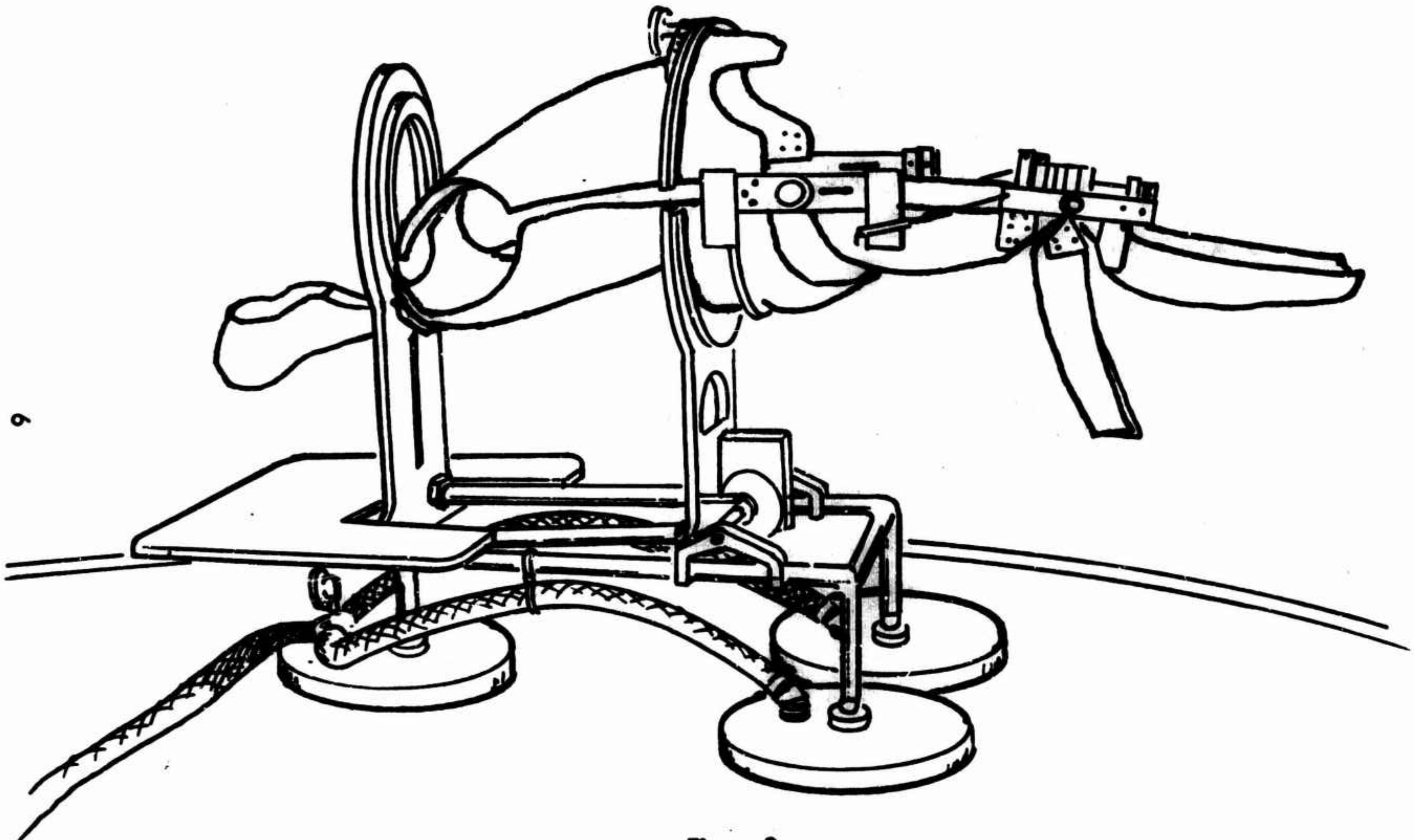


Figure 2

Air–Bearing Device Supporting Subject When Horizontal to Axis of Rotation and Allowing Subject Freedom to Rotate about Long Axis, Move Head and Limbs, and Carry Out Required Activities

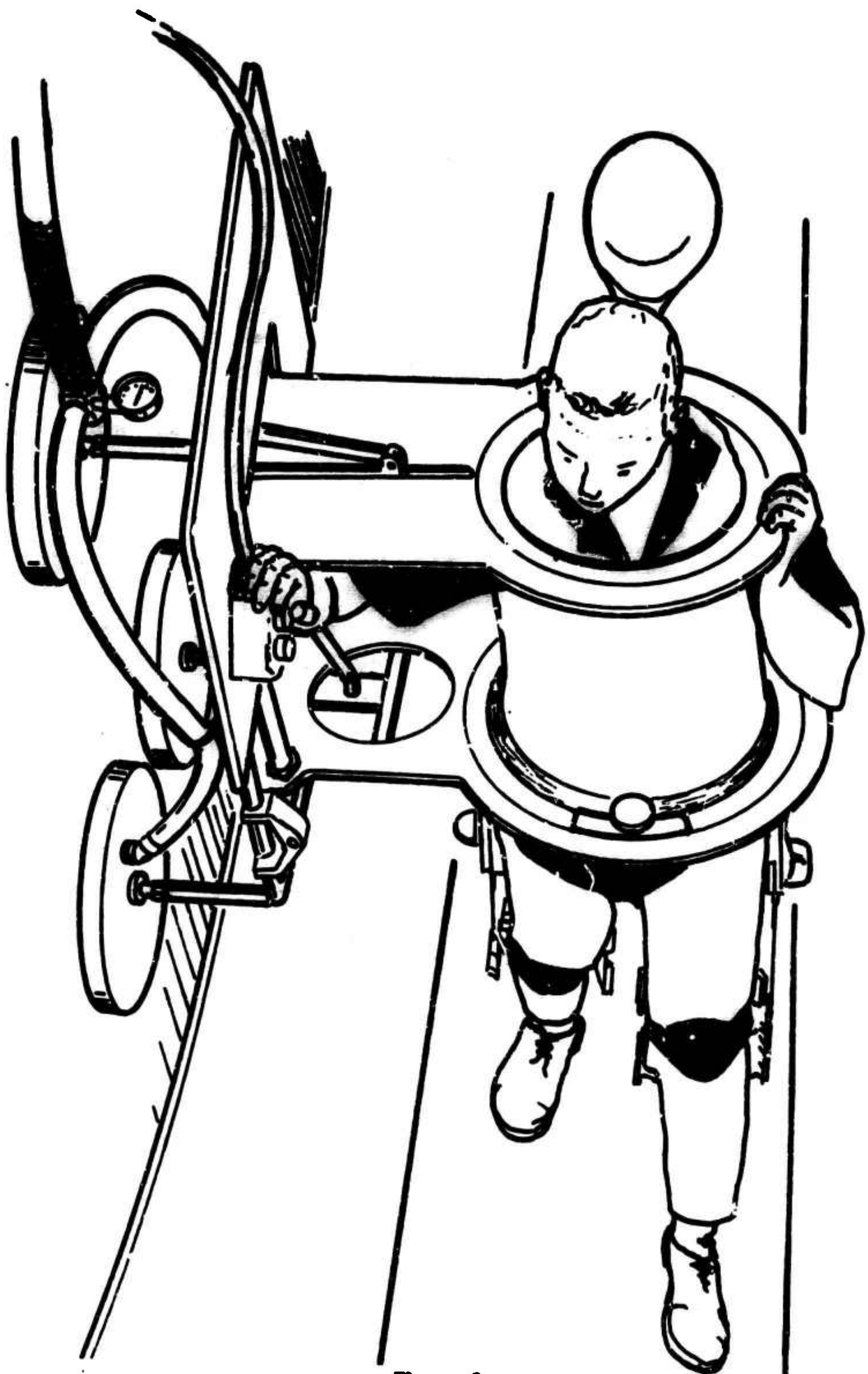


Figure 3

Subject Walking in Air-Bearing Device. Orientation accords with direction of "up-down" in long axis of body.

Gravitational force. — The force acting on the subject opposing the acceleration of gravity of the Earth is an undesirable factor from the standpoint of this experiment; however, the use of the air-bearing device minimized the effects of this force along the long axis of the body for the horizontal orientation or fractional G.*

Centrifugal force. — This is the force opposing the centripetal acceleration of the subject's mass when he is constrained to a rotating environment. Centrifugal force derives from $r\omega^2$ where r = radius and ω = angular velocity; or, when expressed in G units, $F_C A_n = 0.000341\ N^2 r$ where N = angular velocity of the room in revolutions per minute; r = radius of rotation to center of mass in feet. At 4 rpm the centrifugal force ranged from 0 at the center to 0.054 G at the periphery (Figure 4) where the gravitoinertial vertical deviated from the Earth vertical by approximately 3 degrees. When the vertically oriented subjects were in a fixed position, they were scarcely aware of this inertial force, and it had negligible effects in terms of circulatory dynamics. In the horizontal mode with the subject supporting his mass through his feet touching the walkway and his Earth weight supported by the ABD, his center of mass was approximately 6 feet from the center of rotation, resulting in a centrifugal force at 4 rpm of 0.035 G. His static position apparent weight was increased by the "weight" of the ABD, or about 5 pounds, and its center of mass was approximately 2 inches from his center of mass along the long body axis and approximately 12 inches from his center of mass across the short axes. For a 200-pound subject his centrifugal force weight under these conditions would be 7 pounds plus the 5-pound ABD "weight," or a total apparent weight of 12 pounds.

Coriolis force. — In 1835, Gaspard G. de Coriolis, a French civil engineer, described the complete significance of the accelerations which apparently acted upon bodies as a result of the rotation of the Earth, and thereafter these "compound centrifugal" forces were known as Coriolis forces. The fundamental law relating the time rate of change of a vector, as measured by an observer in space rotating with respect to the reference space, may be expressed mathematically by the vector equation:

$$\left(\frac{d\overline{V}}{dt}\right)_r = \left(\frac{d\overline{V}}{dt}\right)_m + (\overline{\omega}_{rm} \times \overline{V})$$

where

$(d\overline{V}/dt)_r$ = change in velocity vector with respect to the reference space
$(d\overline{V}/dt)_m$ = change of velocity vector with respect to moving space
$(\overline{\omega}_{rm} \times \overline{V})$ = change of velocity vector due to rotation of moving space

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*The capital letter, G, is used as a unit to express inertial resultant to whole-body acceleration in multiples of the magnitude of the acceleration of gravity, g_o, which is 980.665 cm/sec² or 32.1739 ft/sec². Hence, Earth weight multiplied by the G units of any of the other forces acting on a subject gives the magnitude of the force.

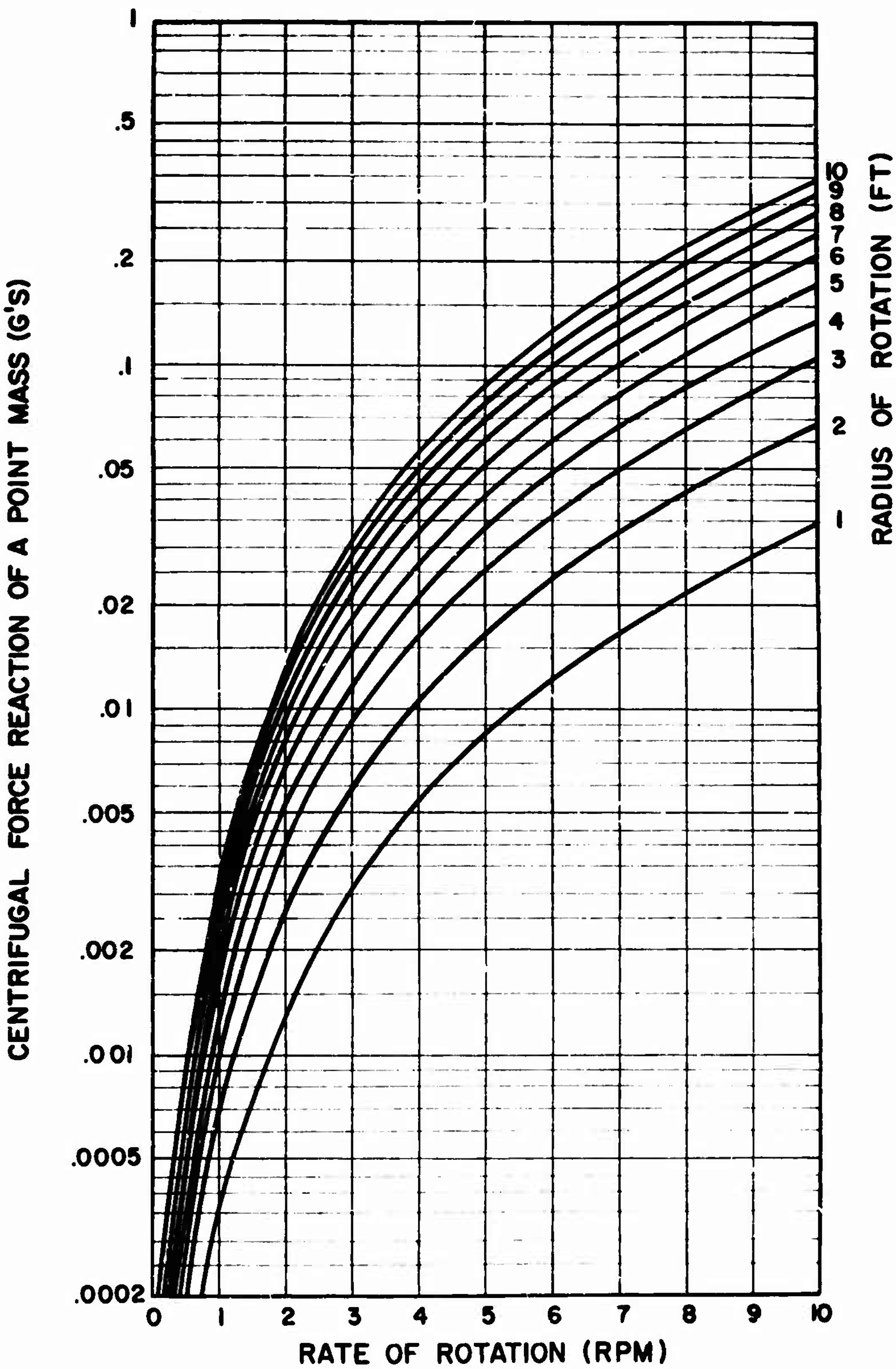

Figure 4

Centrifugal Force Reaction of a Mass in a Rotating Environment. Force in pounds = Earth gravity weight x G units.

To a subject in the rotating environment this acceleration or force vector may manifest itself in two ways. First, it adds to the apparent weight of a body moving with, or in, the direction of rotation and subtracts from the apparent weight when moving against the direction of rotation. Second, when a body moves toward the center of rotation, the Coriolis force is exerted in the direction of rotation at right angles to the body's motion; when moving away from the center of rotation, the force is opposite to the direction of rotation. A motion parallel to the axis of rotation will generate no Coriolis acceleration. The value of Coriolis acceleration in G units for a body moving perpendicularly to the axis of rotation in a spinning system may be determined by:

$$F_{(\text{Coriolis})} = 0.00651\ V\ N$$

where:

V = velocity of body relative to rotating vehicle in ft/sec
N = vehicle rate of rotation in revolutions per minute

For any motion not exactly perpendicular to the axis of rotation the component of the velocity that is perpendicular is used to determine the Coriolis force; hence, the value must be multiplied by the sine of the angle between the angular rotation rate vector and the velocity vector.

Figure 5 illustrates the Coriolis force in G units for various rates of movement perpendicular to the axis of rotation at various rates of the room's rotation. Coriolis force plus the centrifugal force influence the ataxia exhibited by subjects. From Figures 4 and 5 it is apparent that at 4 rpm a person in the horizontal mode walking in the direction of spin at about 2 ft/sec reaches zero apparent weight and no traction results. When walking with the direction of rotation, a much higher walking velocity is possible. Also, moving toward the center facing against the direction of spin produces a tendency to pitch backward, and moving toward the periphery produces a tendency to pitch forward. These, of course, would be reversed when facing with the spin direction.

The semicircular canals are structured to respond to Coriolis accelerations with movement of the head out of the plane of rotation of the room (16). The changing patterns of Coriolis forces affecting the cupula endolymph system for the several canals associated with different head movements have never been calculated. Limited treatments involving different concepts have been presented (23, 25, 26). It is sufficient here to deal in terms of angular velocity of the SRR and "head movements." In this experiment the Coriolis forces were complicated by direct and indirect effect related to the subject's orientation.

<u>Vestibular Stimulation in the Vertical and Horizontal Modes</u>

It is necessary to make a distinction between fine and gross bodily activities. Fine movements include rotations of the head which generate stressful Coriolis

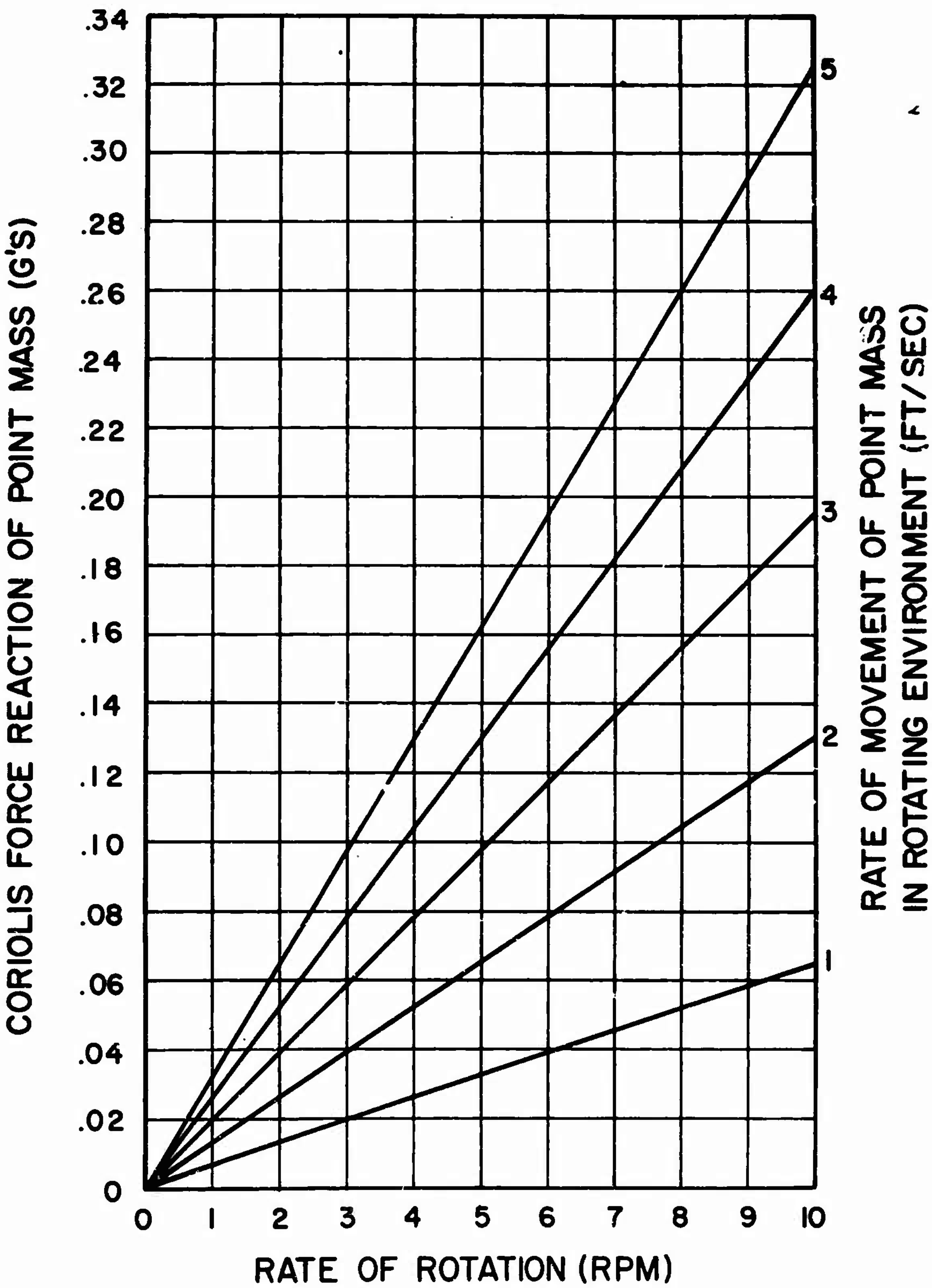

Figure 5

Coriolis Force Reaction of a Mass Moving in a Rotating Environment. Force in pounds = Earth gravity weight x G units.

accelerations stimulating the vestibular organs but are otherwise relatively unimportant. Gross movements affect not only the vestibular organs but also nonvestibular proprioceptor systems which influence postural equilibrium and taxis.

With regard to the semicircular canals the angular or Coriolis accelerations generated by rotary motions of the head would be the same whether a person was in the vertical or horizontal mode. Nevertheless, several factors may account for differences in response in the two modes. One factor is the so-called "free movement," i.e., rotation of the head in the same plane as the room's rotation, which does not generate stressful levels of Coriolis accelerations. The free movement when a person is upright is a right or left rotation; while in the horizontal mode, it is a flexing motion in the plane of rotation. A second factor is concerned with the possibility that for comparable levels of Coriolis accelerations generated by head movements, the more stressful in terms of response would occur with man in the horizontal mode. A third factor deals with the possibility that the canals are directly influenced by the magnitude and direction of the gravitoinertial load. As indicated above, there is ample evidence of an influence, but it is not completely clear whether this is a direct effect, or the modulating effects via otolithic stimulation, or both.

With regard to the otolith organs there is much evidence that their effects on behavioral responses are greatly influenced not only by their orientation with respect to the resultant force vector but also by its magnitude. In terms of their influence on egocentric visual localization of the horizontal they contribute much when man is upright and less when he is horizontal (24).

Effectiveness of Simulation in the Present Experiment

SRR sickness. — Until validating observations have been made aloft, the degree of effectiveness will not be known. One aspect simulated quite accurately was the orientation of the canals with respect to the axis of rotation. The free movement might be a little more difficult to determine in a rotating spacecraft than in the SRR inasmuch as the "floor" of the spacecraft does not provide the necessary orientation cue. The otolith influences would be different in the two conditions, and the role of each deserves investigation. It should be mentioned that in the SRR, the subject in the horizontal mode was restricted in types of movements to a greater degree than he would be in a rotating spacecraft, but to some extent this was controlled by exposing him in both horizontal and vertical modes in the SRR.

Ataxia. — In the experiment with man vertical, the simulation was poor with reference to the subgravity conditions in the spacecraft. In the horizontal mode the subject was supported by the air-bearing device; postural equilibrium was never a problem when he was static. While he was walking, postural equilibrium was aided by the ABD; hence, simulation of spacecraft conditions was only fair.

TESTS AND RESULTS

General Health

This experiment involved four subjects and many experimental devices over a period of three months, and neither illness of subject nor breakdown of equipment faulted the experimental findings. The subjects were under constant surveillance of the on-board physician, and, in addition to a brief medical evaluation each morning, certain routine determinations and special tests reflected the general fitness of the subjects. Routine daily determinations included body temperature, pulse and respiratory rates, blood pressure, urinalysis, and examination of blood films. These tests did not reveal any unexpected findings.

The results of tilt table tests are of twofold significance, first as an indication of "deconditioning" and, second, as a factor influencing performance in the ataxia test battery. Tilt table tests were conducted daily when the subjects were in the vertical mode. Nine pulse rate and blood pressure readings were obtained during a fifteen-minute backward tilt 20 degrees from the vertical with the subject's weight on his feet. The measurements were reduced to standard scores, and any change of two sigma from the control values was considered significant. Two subjects manifested slight changes. RO on the first day of rotation had a slight rise in systolic blood pressure on tilt-up, not accompanied by changes in diastolic pressure or pulse rate; this rise was noted on one measurement and its consequences insignificant. BR on change in mode from horizontal to vertical during rotation had a slight temporary fall in systolic and diastolic pressure the first day on tilt-up and a slight fall limited to the systolic pressure on the second day; the consequences of these changes were insignificant. Slight changes in baseline levels in pulse rate were noted.

SRR Sickness

This term is used to indicate motion sickness occurring in a rotating room or similar device. Unlike turbulent conditions at sea or in the air, the stressful stimuli cease on fixation of the head with reference to the room, and a subject can, by this means, become symptom free, the while remaining "susceptible." This makes it difficult to follow the precise course of habituation and adaptation. Consequently, in the present experiment, both the symptoms manifested in the course of daily activities ("incidental symptoms") and symptoms manifested in response to experimenter-paced head movements ("forced symptoms") were recorded with the aid of a motion sickness questionnaire.

The response to experimenter-paced head movements was determined using a modification of the dial test (13). A "movement" consisted of a rotation or flexion of the head away from its usual position, with reference to the thorax, and return. Five different standardized head movements, not in the plane of the room's rotation, constituted a "sequence." The subject was required to complete either 50 or 100 sequences. A motion sickness rating method (11,14) was used to indicate the level of severity of symptoms.

Clinical signs and symptoms. — The findings are summarized in Figure 6. Points on the curves indicate the severity of incidental symptoms; if solid, circles or squares on the curves indicate the severity of forced symptoms resulting from 100 sequences of head movements; if half solid, they indicate 50 sequences.

Severe symptoms were experienced only during the first day of rotation. In the the first experiment, BR's symptoms were aggravated by having him change from the horizontal to the vertical mode to perform an ataxia test, a test subsequently not repeated under this circumstance. Forced head movements, until the subjects were habituated to rotation, were an important factor in raising the level of severity of symptoms. At the beginning of the second day perrotation, symptoms were absent or inconsequential even during forced head movements, except in the case of TU.

All of the subjects in all of the experiments were free of subjective symptoms and manifested no signs of SRR sickness prior to change in mode during rotation. After the change in mode, even forced head movements did not evoke symptoms in experiments 1 and 4, and in 2 and 3 the symptoms were trivial.

On cessation of rotation forced symptoms were insignificant except for TU in the third and JO in the fourth experiment, and then they were mild. Individual variances were demonstrated, TU and JO being the more susceptible members of the two pairs and TU more susceptible than JO.

A comparison between susceptibility to SRR sickness in the two modes is complicated by an order effect and, probably, by greater incidental activity in the vertical than in the horizontal modes. With these factors taken into account, the differences in susceptibility demonstrated were small. Transfer of habituation from one mode to the other during rotation was good.

Clinical and Biochemical Tests

Blood samples were drawn each day, and hemoglobins, hematocrits, and leucocyte counts were made. Total urine outputs were collected not only for routine testing but also for the determination of hourly excretion rates of 17-hydroxycorticosteroids (21) and the catechol amines, epinephrine and norepinephrine (5). Aliquots of the urines were stabilized at pH 1-2 and frozen for the analyses of these compounds at a later time. A record of the volumes of all fluids consumed was kept for each subject.

Fluid balance. — In Figures 7 and 8 are shown the mean values for fluid intakes, urine outputs, hemoglobins, and hematocrits for all subjects with the same change in mode. It is seen that fluid inputs and outputs decreased and hemoglobin and hematocrit values increased significantly only when subjects were in the horizontal mode during rotation. Since a change in position was not involved, in the start-horizontal mode the alterations were probably attributable to vestibular influences as demonstrated in previous experiments (4). In the start-vertical mode, significant alterations appeared only after shift to the horizontal mode. If poor transfer of vestibular habituation was a

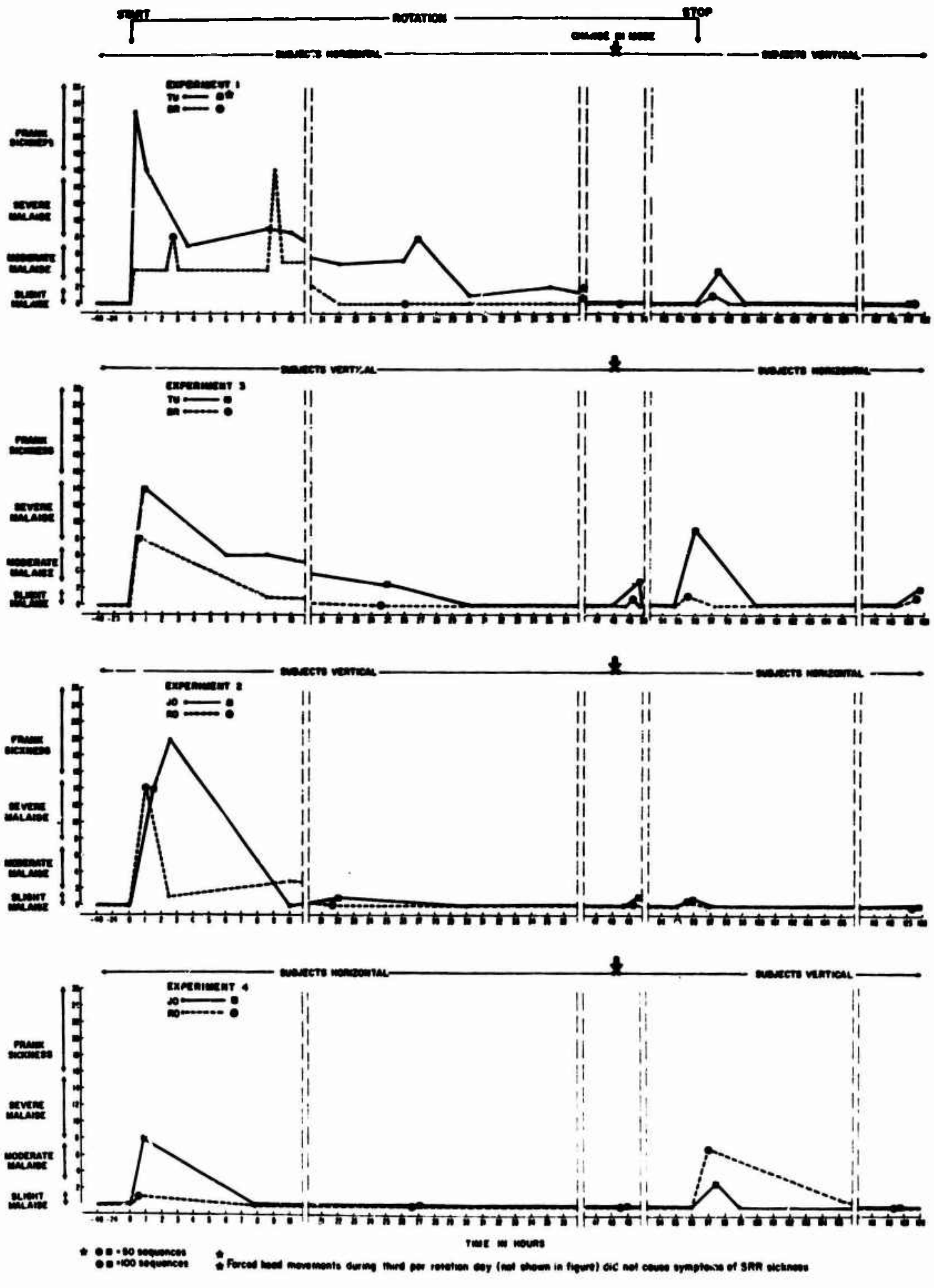

Figure 6

Changes in Severity of Clinical Manifestation of SRR Sickness as Functions of Length of Exposure to 4 rpm, Perrotation Change in Mode, and Cessation of Rotation. Points on the curve refer to "incidental" and squares or circles to "forced" symptoms. See text.

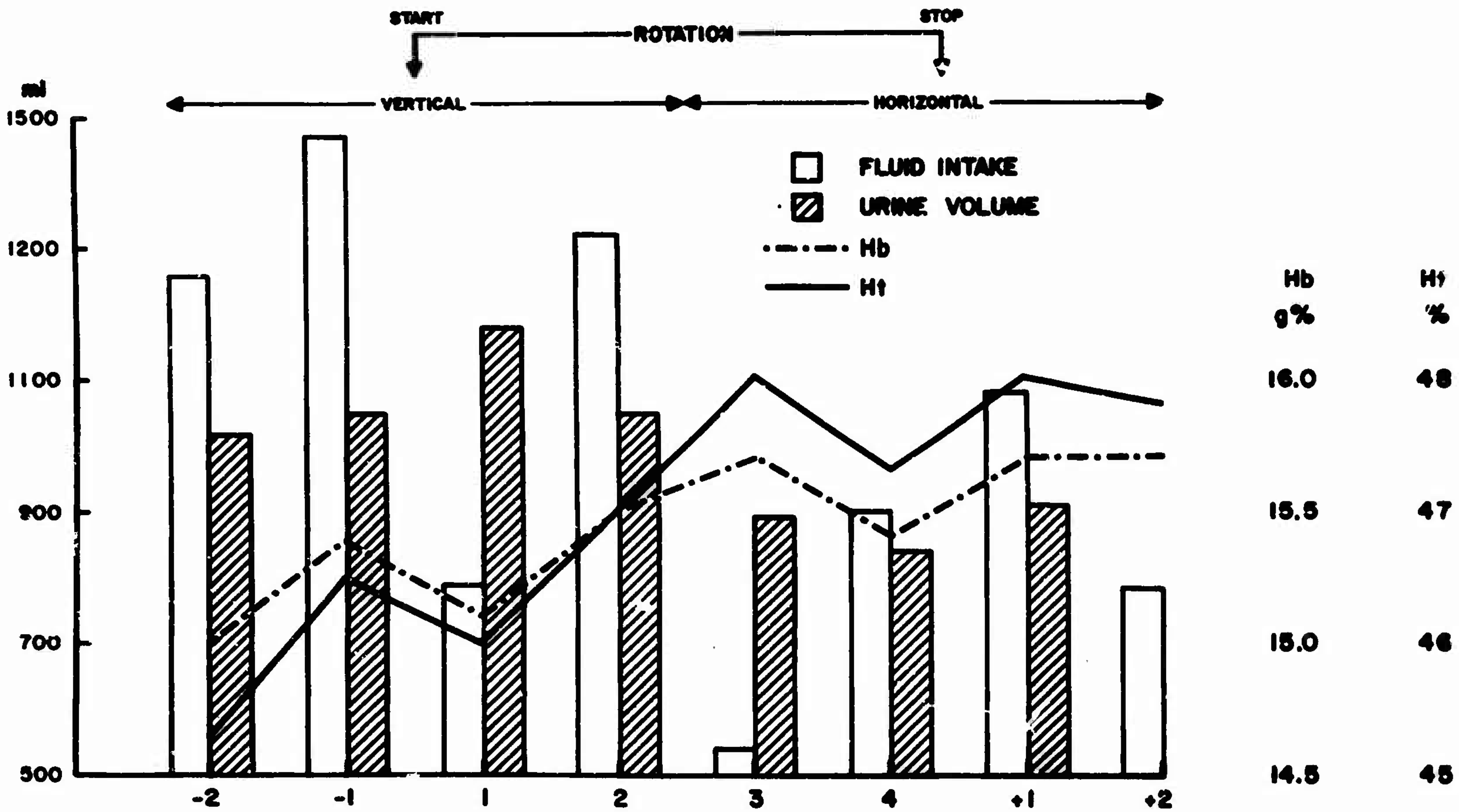

Figure 7

Comparisons Between Mean Values for Four Subjects' Fluid Intake-Output and Changes in Hemoconcentration During the Entire Experimental Period in Two Start-Vertical Experiments

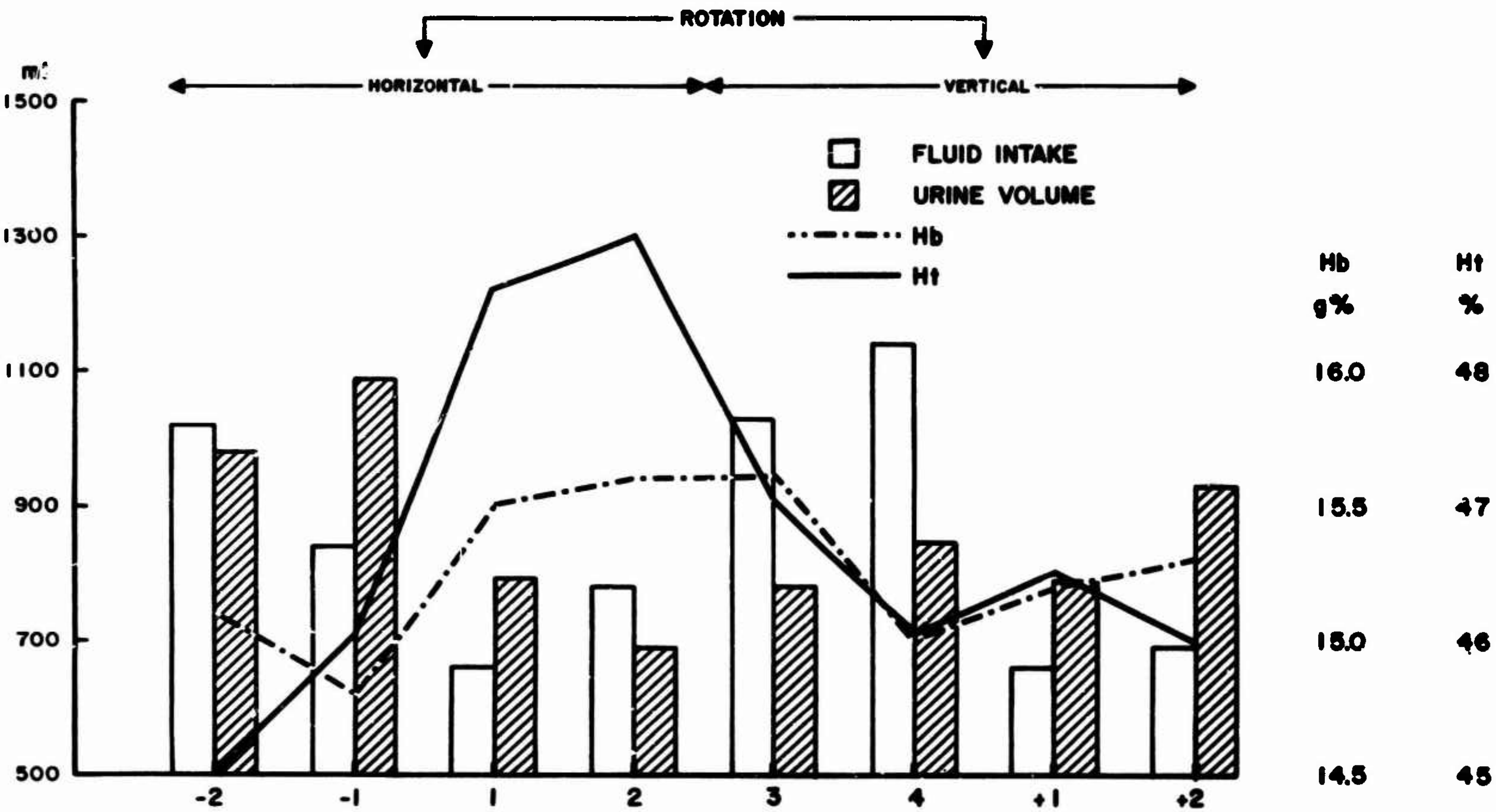

Figure 8

Comparisons Between Mean Values for Four Subjects' Fluid Intake-Output and Changes in Hemoconcentration During the Entire Experimental Period in Two Start-Horizontal Experiments

contributing factor in these alterations, this would have interesting implications; e.g., the clinical signs and symptoms would have limitations as predictors of complete vestibular habituation. Although past experience (15) suggests that such a limitation is indeed demonstrable, the low level of stressful Coriolis accelerations in the present experiment renders vestibular influences an unlikely significant factor.

Catechols and corticoids. — Figures 9 and 10, respectively, show mean changes in the excretion rates of the biogenic amines, epinephrine and norepinephrine, for all subjects in the start-vertical and start-horizontal positions. Change in body position from vertical to horizontal during rotation produced the most significant changes in excretion rates of the catechols. When body position changed from horizontal to vertical, there was no significant change in trend of catechol release; however, on the last day of the experiment a slightly elevated rate of catechol excretion was noted in the finish-vertical mode.

Corticoid excretion rates showed two well-defined peaks during the experiments when subjects initially were in the horizontal mode, one on the day of the start of rotation and one on the day before rotation ceased (Figure 11). Again, as with the catechols, the steroid response in the second set of conditions was less well related to a change in experimental conditions.

The vestibular influences which may have slightly affected the excretion rates are almost impossible to separate from other influences, partly because the vestibular influences were mild.

Psychophysiological Tests

Hand dynamometer. — A subject's daily score was the single best of three trials employing a standard model Stoelting.

Performances became slightly worse during the first two days of rotation, improved slightly after body mode was changed each time during rotation, but did not change systematically after rotation ceased (Figure 12).

Hand steadiness. — Drilled in a vertical aluminum plate 10 by 14 inches were three holes (0.250, 0.199, and 0.188 inch in diameter) into which subjects inserted a stylus 0.042 inch in diameter. The number of times the stylus contacted the sides of the holes was registered on a counter. Three sixty-second trials were administered for each hole, and the mean of means constituted the score.

Some improvement was observed during the first two days of rotation in both the horizontal and vertical modes, but mean performances did not change systematically during the remainder of the experimental period (Figure 12).

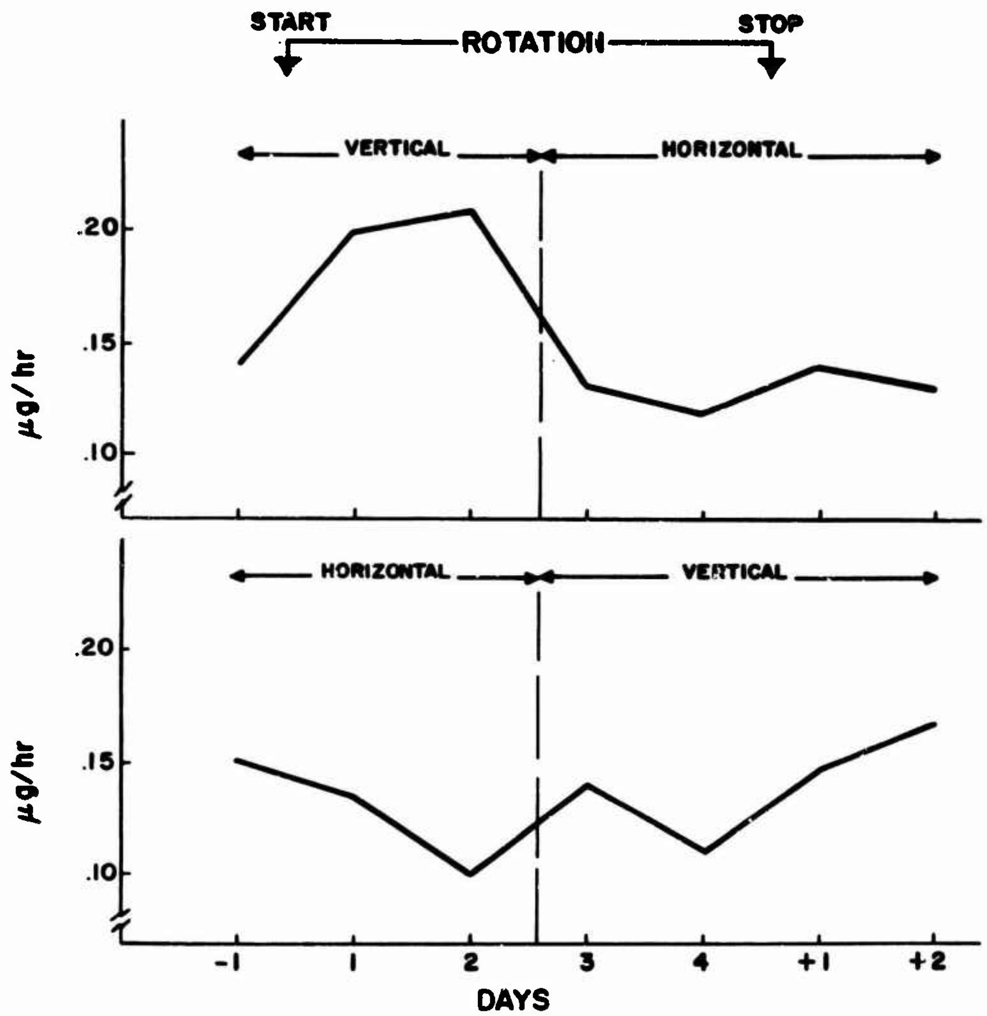

Figure 9

Mean Changes in Excretion Rates of Epinephrine for Four Subjects
Throughout Entire Experimental Period

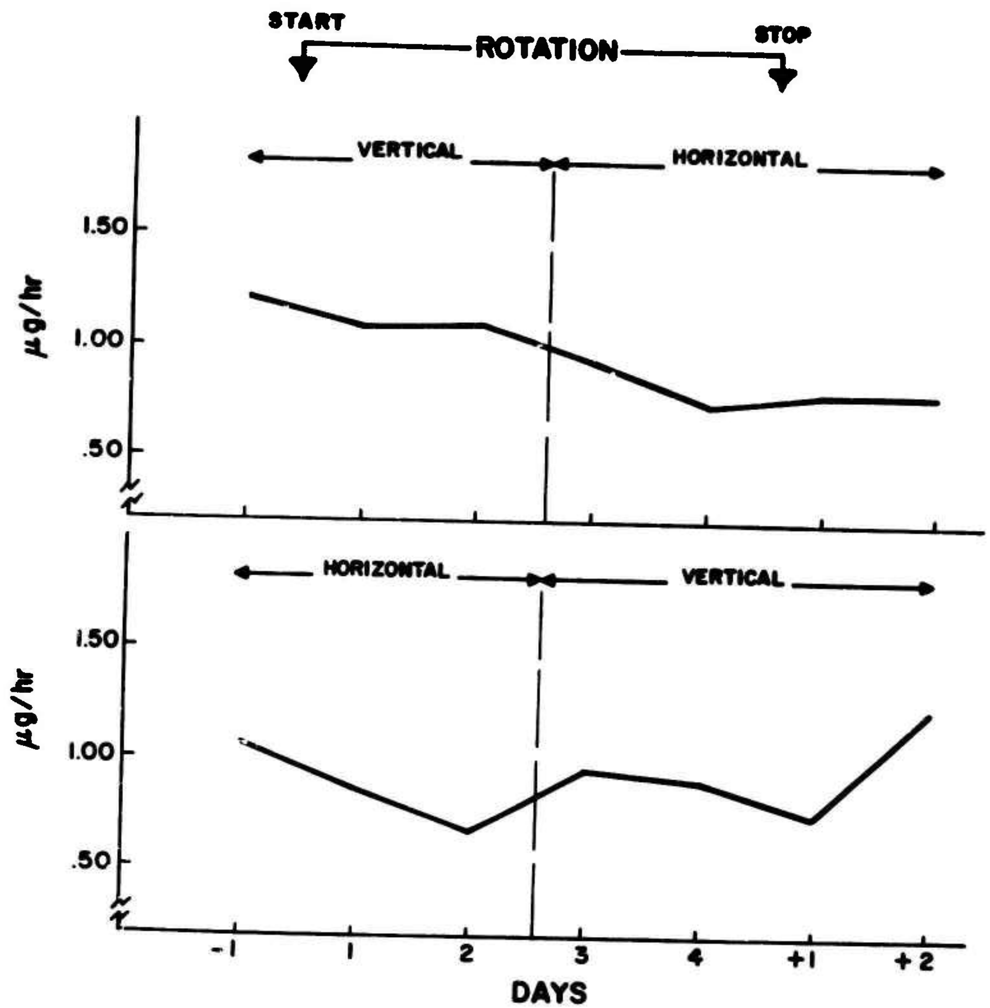

Figure 10

Mean Changes in Excretion Rates of Norepinephrine for Four Subjects Throughout Entire Experimental Period

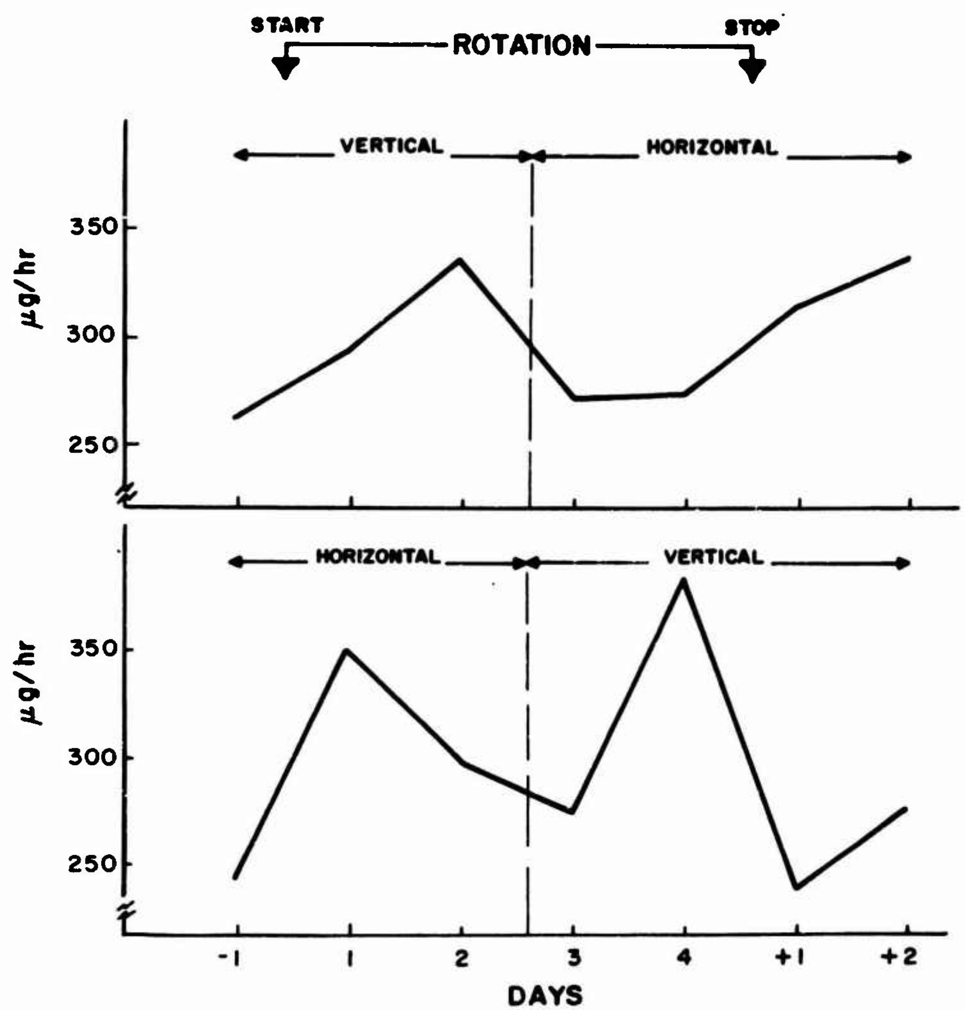

Figure 11

Mean Changes in Excretion Rates of 17-hydroxycorticosteriods for All Subjects in the Start-Vertical and Start-Horizontal Modes

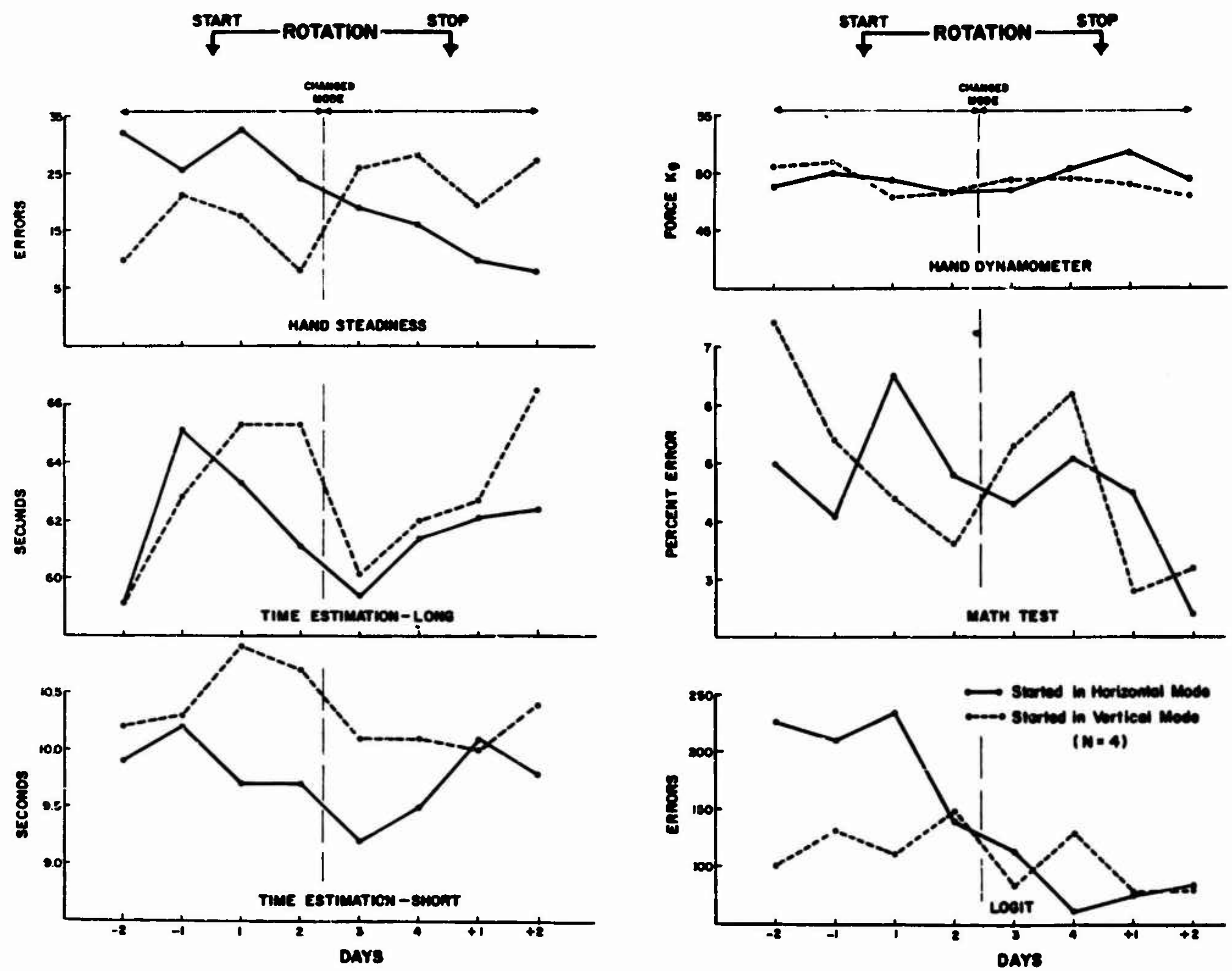

Figure 12

Changes in Mean Scores for All Subjects in Psychophysiological Tests in the Start-Horizontal and Start-Vertical Modes

Time estimation (60 seconds and 10 seconds). — Subjects were required to depress a switch to activate a Standard Timer Model S-1. Five judgments were scored for each time period.

Sixty-second performances (time estimation-long) improved slightly during the first two days of rotation; they became worse after body mode was changed on each run during rotation, and performance again improved when rotation stopped (Figure 12).

Ten-second performances (time estimation-short) decreased slightly during the first two days of rotation but did not change systematically during the remainder of the experimental period (Figure 12).

Math test. — Four nixie tubes displayed in a rectangular configuration were energized in pairs by a step relay. The subject indicated his answers to variously difficult and randomly presented addition, subtraction, and multiplication problems by means of an electric adder. The 336 problems presented were scored in terms of errors.

Performances did not change systematically during rotation but improved considerably when rotation stopped (Figure 12).

Logit. — The logical inference test (Logit) designed by French (9) was used to measure performance involving higher mental processes. The subject faces a console with 20 buttons arranged in four rows, which are illuminated when pressed. His task is to learn the order in which the button should be pressed to solve a particular "problem." The experimenter can program an almost unlimited number of problems and monitor the time required and extra buttons (errors) pressed.

Performances did not change systematically during the first two days of rotation but improved slightly to considerably during the remaining experimental period, as seen in Figure 12.

Discussion. — With practice effects and the expected day-to-day variance under controlled conditions taken into account, there appeared to be a slight decrease in strength of grip during the first two days of rotation. A slightly lower performance perrotation compared with postrotation was demonstrated in the Logit and math test scores. There were no order effects, i.e., no differences in scores between the start-horizontal and the start-vertical modes in any of the tests. These minimal differences in performances were not unexpected in the light of previous findings (15).

Postural Equilibrium and Locomotion

The original intention was to administer quantitative tests (8, 12) throughout the entire experimental period, but the first attempt in the first experiment demonstrated that it was neither feasible nor desirable during the perrotation period when subjects were in the horizontal mode. Rough estimates, however, were made perrotation (vertical mode) whereas a standard ataxia test battery was used before and after rotation.

The test items were administered in the following sequence: 1) Sharpened Romberg (SR) consisting of standing on the floor with eyes closed for 60 seconds; 2) rail walking and standing; 3) standing on one (each) leg on the floor with eyes closed for 30 seconds (SOLEC-R and SOLEC-L); 4) walking a 12-foot line on the floor with eyes closed (WALEC), scored as inches of deviation from the line. Rail walking and standing consisted of 1) walking with eyes open (Walk E/O on a 3/4-inch by 8-foot rail, scored as number of steps (maximum of five steps per trial); 2) standing with eyes open (Stand E/O on the 3/4-inch rail, scored to the nearest second (maximum of 60 seconds per trail); and 3) standing with eyes closed (Stand E/C) on a 2-1/4 by 30-inch rail, also scored to the nearest second with a maximum of 60 seconds per trail. The body position required of all subjects was: (a) body erect or nearly erect; (b) arms folded against chest, and (c) feet, shoes on, tandemly aligned heel-to-toe (SOLEC excepted).

Prior to rotation there were five to eight "practice sessions" to establish plateaued baseline scores. After cessation of rotation the subjects moved as little as possible until the test was made; in the finish-vertical mode they were tested 5.5 hours and again 29.5 hours later. In the finish-horizontal mode subjects remained in their molds as if rotation had not been discontinued. In other words, they were upright for only a few minutes until tested on a single occasion 36 hours after cessation of rotation.

Results. — 1) Perrotation: These limited findings consist of the subjects' reports and the observer's impressions of their facility in walking in the vertical mode. With the onset of rotation when the subjects were in the vertical mode, all had difficulty in walking. This difficulty greatly diminished during the first day and was minimal on the second. At the time for change in mode there was no doubt but that habituation and adaptation had occurred, although no attempt was made to demonstrate it quantitatively. The possible influence of this adaptation on change to walking in the horizontal mode was not determined.

With the onset of rotation in the horizontal mode, especially in the first experiment, the subjects gradually acquired skill in walking under the unusual conditions. On change to the vertical mode two days later they were ataxic. It was evident that the vestibular habituation rendering them insusceptible to SRR sickness did not greatly influence their susceptibility to ataxia.

(2) Pre- and Postrotation: The quantitative ataxia test findings on each of the four subjects before and after rotation (Table II) were highly representative of findings from the group as a whole, as summarized* in Figure 13. In making comparisons between postrotation scores when subjects were either "finish-horizontal" or "finish-vertical," differences between physical activities in these modes should be kept in mind. Ataxia test battery performances were impaired during all postrotation test periods, but considerably more so during the test period following the finish-horizontal mode of rotation.

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*Except Walk on Floor Eyes Closed, which did not change quantitatively.

Table II

Individual and Mean Effects on Postrotation Ataxia After Habituation in Each of Two (Vertical and Horizontal) Modes During Exposure to an Angular Velocity of 4 rpm on Four Normal Subjects

	Rotation Mode																			
						Horizontal					Vertical									
Ataxia Test Battery	Baseline Scores					36 hr-Postrotation					5.5 hr-Postrotation					29.5 hr-Postrotation				
Subjects:	JO	RO	BR	TU	$\overline{X}$	JO	RO	BR	TU	$\overline{X}$	JO	RO	BR	TU	$\overline{X}$	JO	RO	BR	TU	$\overline{X}$
Sharpened Romberg*	207	240	240	237	231.0	80	179	187	240	171.5	122	240	N.T.**	N.T.	163.0	240	240	240	240	240.0
Walk Eyes Open on a $\frac{3}{4}$-in. wide rail	15	15	15	15	15.0	14	15	15	15	14.8	15	15	14	15	14.8	15	15	14	15	14.8
Stand Eyes Open on a $\frac{3}{4}$-in. wide rail	86	103	73	101	91.0	16	56	23	34	32.3	40	103	45	36	56.0	44	154	37	39	68.5
Stand Eyes Closed on a $2\frac{1}{4}$-in. wide rail	159	180	180	173	173.0	31	158	180	86	113.8	134	180	180	79	145.8	136	180	180	180	169.0
Stand One Leg Eyes Closed-R	146	148	135	149	144.5	62	150	150	113	118.8	150	150	N.T.	N.T.	150.0	150	150	150	150	150.0
Stand One Leg Eyes Closed-L	145	138	141	145	142.3	85	145	106	82	104.5	91	150	N.T.	N.T.	120.5	150	150	133	150	145.8
Walk a Line Eyes Closed+	12	11	9	10	10.5	6	4	8	16	8.5	18	9	34	9	17.5	10	2	6	7	6.3

*Standing heel-to-toe on floor eyes closed.

+12-foot length on floor heel-to-toe.

**Not tested.

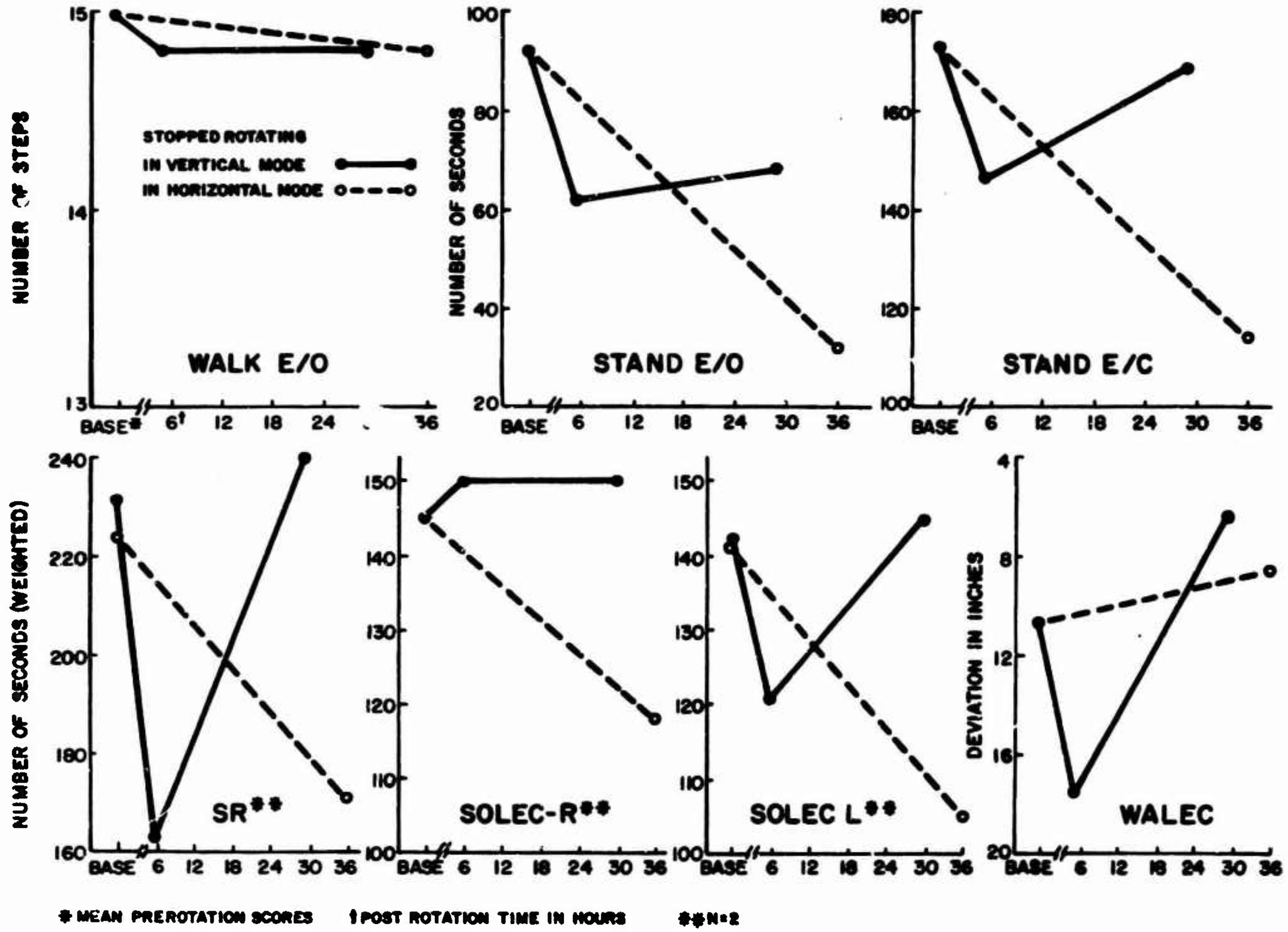

Figure 13

Mean Effects on Postrotation Ataxia After Habituation in Each of Two (Vertical and Horizontal) Modes During Exposure to an Angular Velocity of 4 rpm on Four Normal Subjects. (See text for explanation of tests.)

(a) 36 Hours After Finish-Horizontal: Marked performance decrements were found on all except the two walking tests. On the Walk E/O test, subject JO had lost only "one step," and on the WALEC test subject, TU deviated only slightly more (6 inches total) than he did before rotation. Positive results in terms of the five standing tests were as follows: on the Stand E/O test the scores of all four subjects showed marked declines; on three tests (SR, Stand E/C, and SOLEC-L) three of the four subjects had substantial performance deficits; and on the remaining test (SOLEC-R) the scores of two of the subjects, JO and TU, who showed impairment also in walking, showed marked decreases from baseline levels.

(b) 5.5 and 29.5 Hours After Finish-Vertical: Performance decrements were found on all of the tests, except SOLEC-R, after 5.5 hours. Frequency of performance improvements on the remaining tests were as follows: SR (all four subjects), Stand E/C and WALEC (two subjects each), and SOLEC-L and Walk E/O (each subject).

After 29.5 hours mean performance on all tests, except Stand E/O, had recovered to or surpassed baseline levels. All four subjects had recovered their scores on the SR, SOLEC-R, and WALEC tests, and three of the subjects had recovered on the Walk E/O, Stand E/C, and SOLEC-L tests. The recovery of only one subject on the Stand E/O test is probably in part a reflection of its having the greatest "top" among the tests.

<u>Discussion</u>. — Walking test performances were less affected by rotation than standing test performance. This differential result may reflect the fact that 1) the walking tests had less "top," i.e., were less difficult than the standing tests in terms of the ease with which maximum scores were obtainable; and 2) the process of walking afforded greater opportunity for adaptation to the static environment. For example, on the first trial of the <u>Walk A Line Eyes Closed</u> and <u>Walk on Floor Eyes Closed</u> tests, the feet swung and landed opposite to the intended direction on each step and almost caused the subject to side-step, but only a short time later, or on the second or third trial, the subjects had quickly learned appropriate corrective maneuvers, resulting in scores not far from the initial values. On the standing tests the return to normal was severely hampered by the finer motor adjustments needed for the more precarious maintenance of postural equilibrium. On the narrow rail, particularly, errors in corrective head and body motions were poorly tolerated, even in the presence of vision.

Characteristically, the subjects felt that their body balance had returned to normal long before the objective, stringent ataxia test procedures demonstrated its return to normal. Postural hypotension was ruled out as a factor influencing the results. There were no systematic order effects; i.e., results of initial exposure to rotation in the vertical mode did not differ essentially from results of initial exposure to rotation in the horizontal mode.

GENERAL DISCUSSION

With regard to SRR sickness, our findings clearly demonstrated that habituation in one mode transferred to the other. It is particularly noteworthy in the case of change from the horizontal to the vertical mode inasmuch as the subjects when in the former mode actually remained horizontal for all but a few minutes of each 24 hours. Previous experiments conducted in the SRR are worth a brief mention in this connection. These were of two sorts. One involved prolonged exposure without restriction on bodily activities; the onset of rotation began in the morning and most of the day's activities were carried out with the participants seated or upright. There were no "anecdotal" reports of an increase in severity of symptoms with change to the recumbent position, although, on occasion, frequent head movements were made during recumbency.

In another type of experiment (17) head movements, with subject seated upright, were restricted to a single tilt, in the frontal plane, away from the upright and return. This movement was repeated until symptoms including SRR sickness in a number of subjects were abolished. It was found that habituation of nystagmus and the oculogyral illusion did not transfer to tilt of the head in the opposite direction. Although the experimental design did not permit a sufficient number of head movements on the unpracticed side to induce nausea, this would have been a reasonable expectation in a susceptible subject. In a somewhat similar study Dowd and Cramer (7) reported that of subjects demonstrating transfer of habituation of nystagmus most did not demonstrate any significant transfer with regard to "visual reactions." Thus, it remains to be determined what the minimal number of single practiced head movements would be to ensure universal transfer of habituation of motion sickness in a rotating environment.

The phenomenon of transfer effects on exposure to force environments which differ qualitatively or quantitatively from one another has been a topic of much interest but little study. Incidental observations are of little value and few systematic studies have been conducted (6).

Our findings have practical significance in terms of habituation of astronauts under terrestrial conditions for exposure aloft in rotating spacecraft. It would appear that as good a protection against SRR sickness aloft is provided with subjects habituated in the upright as it is in the horizontal mode. Also, within the experimental limits mentioned above, it justifies the extrapolation of findings obtained in earlier SRR experiments to conditions in rotating spacecraft. In the spacecraft, however, there would still exist differences compared with terrestrial conditons due to cancellation of Earth gravity. The level of artificial gravity generated would need to be taken into account.

Just as our findings were clear cut regarding transfer effects in connection with SRR sickness, they were almost equally clear cut with regard to postural disequilibrium, although the "disturbing variables" were not the same. Walking and standing involved nonvestibular proprioceptor as well as vestibular mechanisms, and whatever habituation was acquired walking and "standing" in the horizontal mode either was incomplete or,

if complete, transfer was poor. Although taxis is not so important an operational problem as SRR sickness, nonetheless, elucidation of the underlying mechanisms is of practical importance in the preparation of astronauts for exposure to rotation environments aloft and is also of theoretical interest.

The chief finding of scientific interest was the preservation of postural habituation to the rotating environment long after cessation of rotation. The phenomenon had been noted previously (13,15,17), and the desirability of designing an experiment with this objective in mind was recognized. Although only a few data points were obtained, this does not lessen the significance of the findings from a qualitative standpoint. In short, it was demonstrated that for at least as long as 36 hours after rotation ceased, postural homeostasis to the rotating environment was preserved. The fact that postural homeostasis with respect to the rotating environment was retained while habituation of SRR sickness was lost implicates nonvestibular proprioceptor mechanisms. By greatly restricting the subjects' movements, the dynamics of the homeostatic process involved were rendered static, to a high degree, until the subject became active. Such manipulative opportunities are an advantage in studying the underlying adaptive processes.

REFERENCES

1. Benson, A. J., and Whiteside, T. C. D., The effect of linea. acceleration on the response to angular acceleration in man. J. Physiol., 156:6P-7P, 1961.

2. Bergstedt, M., The effect of gravitational force on the vestibular caloric test. Acta otolaryng., Stockh., 3:551-562, 1962.

3. Clark, B., and Graybiel, A., Human performance during adaptation to stress in the Pensacola Slow Rotation Room. Aerospace Med., 32:93-106, 1961.

4. Colehour, J. K., and Graybiel, A., Biochemical changes occurring with adaptation to accelerative forces during rotation. Aerospace Med., 37:1205-1207, 1966.

5. Crout, J. R., Catechol amines in urine. In: Seligson, D. (Ed.), Standard Methods of Clinical Chemistry. Vol. 3. New York: Academic Press, 1961. Pp. 62-80.

6. Dowd, P. J., Resistance to motion sickness through repeated exposure to Coriolis stimulation. Aerospace Med., 36:452-455, 1965.

7. Dowd, P. J., and Cramer, R. L., Habituation transference in Coriolis acceleration. Aerospace Med., 38:1103-1107, 1967.

8. Fregly, A. R., and Graybiel, A., An ataxia test battery not requiring rails. Aerospace Med., 39:277-282, 1968.

9. French, R. S., and Piatt, J. L., Rater and Logit: devices for assessing crew efficiency under stress. ERR-AN-408. San Diego, Calif.: General Dynamics/Astronautics, Dec. 1963.

10. Gernandt, B., The effect of centrifugal force upon the nerve discharge from the horizontal canal. Acta Physiol. Scand., 21:61-72, 1950.

11. Graybiel, A., The labyrinth and space flight. In: Bedwell, T. C., Jr., and Strughold, H. (Eds.), Bioastronautics and the Exploration of Space. Brooks Air Force Base, Texas: Aerospace Medical Division, Air Force Systems Command, 1966. Chapter XVI.

12. Graybiel, A., and Fregly, A. R., A new quantitative ataxia test battery, Acta otolaryng., Stockh., 61:292-312, 1966.

13. Graybiel, A., Clark, B., and Zarriello, J. J., Observations on human subjects living in a "Slow Rotation Room" for periods of two days. Arch. Neurol., 3:55-73, 1960.

14. Graybiel, A., Wood, C. D., Miller, E. F., II, and Cramer, D. B., Diagnostic criteria for grading the severity of acute motion sickness. Aerospace Med., 39:—, 1968.

15. Graybiel, A., Kennedy, R. S., Knoblock, E. C., Guedry, F. E., Jr., Mertz, W., McLeod, M. E., Colehour, J. K., Miller, E. F., II, and Fregly, A. R., The effects of exposure to a rotating environment (10 rpm) on four aviators for a period of twelve days. Aerospace Med., 36:733-754, 1965.

16. Guedry, F. E., and Montague, E. K., Quantitative evaluation of the vestibular Coriolis reaction. Aerospace Med., 32:487-500, 1961.

17. Guedry, F. E., Collins, W. E., and Graybiel, A., Vestibular habituation during repetitive complex stimulation: A study of transfer effects. J. appl. Physiol., 19:1005-1015, 1964.

18. Guedry, F. E., Jr., Kennedy, R. S., Harris, C. S., and Graybiel, A., Human performance during two weeks in a room rotating at three rpm. Aerospace Med., 35:1071-1082, 1964.

19. Jongkees, L. B. W., and Philipszoon, A. J., Nystagmus provoked by linear accelerations. Acta Physiol. Pharm. Neerl., 10:239-247, 1962.

20. Kennedy, R. S., and Graybiel, A., Symptomatology during prolonged exposure in a constantly rotating environment at a velocity of one revolution per minute. Aerospace Med., 33:817-825, 1962.

21. Kornell, L., An improved, rapid method for free and conjugated 17-hydroxy-corticosteroids in urine. Metabolism, 8:432-440, 1959.

22. Lansberg, M. P., Guedry, F. E., and Graybiel, A., Effect of changing resultant linear acceleration relative to the subject on nystagmus generated by angular acceleration. Aerospace Med., 36:456-460, 1965.

23. Meda, E. (translated by Hope, E. R.), A research on the threshold for the Coriolis and Purkinje phenomena of excitation of the semicircular canals. Translation T 17 I. Defence Research Board. Canada: Defence Scientific Information Service, 1954.

24. Miller, E. F. II, and Graybiel, A., Role of the otolith organs in the perception of horizontality. Amer. J. Psychol., 79:24-37, 1966.

25. Thompson, A. B., Physiological design criteria for artificial gravity environments in manned space systems. In: The Role of the Vestibular Organs in the Exploration of Space. SP-77. Washington, D. C.: U. S. Government Printing Office, 1965.

26. Valentinuzzi, M., An analysis of the mechanical forces in each semicircular canal of the cat under single and combined rotations. Bull. Math. Biophysics, 29: 267-289, 1967.

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13. ABSTRACT

The changing symptomatology manifested by four normal young subjects throught exposure to rotation in a Slow Rotation Room (SRR) was used in studying susceptibility to SRR sickness and transfer effects. A comparison was made between the effects of rotation in the SRR with man parallel (vertical mode) and those when he was at right angles (horizontal mode) to the axis of rotation, the situation in a rotating spacecraft. Attention was focused on motion sickness, ataxia, and the phenomenon of transfer of habituation. Susceptibility to motion sickness was similar in the two orientational modes. Within the limitations of the experiment, the findings regarding SRR sickness indicate that habituation acquired in the SRR in one mode transfers to the other mode. The postrotatory perseveration of postural habituation to the rotating environment long after cessation of rotation shed some light on the underlying homeostatic mechanism involved.

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